

Mass generation from a non-perturbative correction: Massive NS-field and graviton in $(3+1)$ -dimensions

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We show that the massless form fields, in $(4+1)$ -dimensional non-perturbation theory of emergent gravity, become massive in a perturbative phase without Higgs mechanism. In particular an axionic scalar sourced by a non-perturbative dynamical correction is absorbed by the form fields to describe a massive NS field theory on an emergent gravitational pair of $(3\bar{3})$ -brane. Arguably the novel idea of Higgs mechanism is naturally invoked in an emergent gravity underlying a CFT_6 . Analysis reveals “gravito-weak” and “electro-weak” phases respectively on a vacuum pair in $(4+1)$ and $(3+1)$ -dimensions. It is argued that the massive NS field quanta may govern an emergent graviton on a gravitational 3-brane.

PACS numbers: 11.25.-w, 11.25.yb, 11.25.Uv, 04.60.cf

Introduction: The general theory of relativity (GTR) is governed by a metric tensor dynamics in 4D underlying a Pseudo-Riemannian manifold. The GTR is a second order formulation and is geometric. It describes an interacting classical theory and hence it rules out the possibility for a perturbation theory. Furthermore the coupled nature of differential field equations in GTR ensures non-linear solutions which are believed to be sourced by a non-linear energy-momentum tensor. Thus the quantum field dynamical correction to GTR urges for a non-perturbation (NP) formulation in second order.

Interestingly the theoretical requirement has been attempted with a dynamical geometric torsion \mathcal{H}_3 in a second order while keeping the Neveu-Schwarz (NS) form onshell in an emergent first order [1–3]. The non-perturbative formulation in a gauge choice has led to an emergent metric which turns out to be dynamical. Generically a geometric torsion in an emergent gravity is a dynamical formulation in 1.5 order, where the metric dynamics can gain its significance at the expense of the non-perturbative dynamical correction [4]. The idea has led to a non-supersymmetric formulation for a NP-theory of quantum gravity in $(4+1)$ -dimensions which may be identified with a stabilized string vacuum on a gravitational pair of $(3\bar{3})$ -brane. In addition need for an extra dimension to the GTR in a NP-theory of gravity is consistent with a fact that a ten dimensional type IIA superstring provides a hint towards a supersymmetric non-perturbation M -theory in eleven dimensions [5, 6].

In the article we present an elegant tool to generate mass for a gauge field by a geometric torsion in a $(4+1)$ -dimensional NP-theory. Generically the NP-tool has been shown to generate a mass for the Neveu-Schwarz (NS) two form on a gravitational pair of $(3\bar{3})$ -brane. In particular a $(3+1)$ dimensional massive NS field quantum dynamics is argued to describe an emergent graviton in the same space-time dimension. It is shown that the local degree of the NP-correction is absorbed by the NS field and hence the axionic scalar in the NP-sector may

formally been identified with a goldstone boson established in Higgs mechanism [7]. Furthermore the emergent NP-theory, underlying a CFT_6 , is revisited with a renewed interest to reveal the Higgs mechanism naturally on a gravitational pair of $(4\bar{4})$ -brane. The emergent $(4+1)$ dimensional curvatures are argued to describe the “gravito-weak” phase of the NP-theory underlying the gravitational and weak interactions respectively on a 4-brane and on a 4-brane. The NP-correction is exploited to realize a duality between a strongly coupled weak interactions and weakly coupled gravity with a cosmological constant.

Glimpse at non-perturbative physics: In the context Dirichlet (D) brane in ten dimensional type IIA or IIB superstring theory is believed to be a potential candidate to describe a non-perturbative world due to their Ramond-Ramond (RR) charges [8]. The D -brane dynamics is precisely governed by an open string boundary fluctuations and the Einstein gravity underlying a closed string is known to decouple from a D -brane. Interestingly for a constant Neveu-Schwarz (NS) background in an open string theory, the $U(1)$ gauge field turns out to be non-linear on a D -brane and has been shown to describe an open string metric [9]. The non-linear gauge dynamics on a D -brane is approximated by the Dirac-Born-Infeld (DBI) action. Various near horizon black holes have been explored using the open string metric on a D -brane in the recent past [10–17].

However the mathematical difficulties donot allow an arbitrary NS field to couple to an open string boundary though it is known to describe a torsion in ten dimensions. A torsion is shown to modify the covariant derivative and hence the effective curvatures in a superstring theory [18, 19]. In the recent past a constant NS field on a D_4 -brane has been exploited for its gauge dynamics in an emergent theory [1–3]. In particular the Kalb-Ramond (KR) field dynamics are used to define a modified derivative \mathcal{D}_μ uniquely. It has been shown to govern an emergent curvatures on a gravitational pair of $(3\bar{3})$ -brane.

The stringy pair production by the KR form primarily generalizes the established Schwinger pair production mechanism [20]. The non-perturbation tool was vital to explain the Hawking radiation phenomenon [21] at the event horizon of a black hole. The novel idea was applied to the open strings pair production [22] by an electromagnetic field. Furthermore the mechanism was explored to argue for the M -theory underlying a vacuum creation of $(D\bar{D})_9$ pair at the cosmological horizon [23].

In particular the stringy pair production by the KR quanta has been explored in diversified contexts to obtain: (i) a degenerate Kerr [24, 25], (ii) a natural explanation to quintessential cosmology [26–29], (iii) an emergent Schwarzschild/topological de Sitter, *i.e.* a mass pair on $(4\bar{4})$ -brane [30, 31] and (iv) a fundamental theory in twelve dimensions and an emergent M -theory in eleven dimensions [4]. Generically the *stringy* nature and the *pair production tool* respectively ensure a quantum gravity phase and a non-perturbative phenomenon. Thus an emergent stringy pair is believed to describe a NP-theory of emergent gravity in 1.5 order formulation. Preliminary investigation has revealed that the NP-theory sourced by a CFT_6 may lead to a unified description of all four fundamental forces in nature. Analysis is in progress and is beyond the scope of this article.

Two form (KR \leftrightarrow NS) dynamics: We begin with the KR form $U(1)$ dynamics on a D_4 -brane in presence of a background (open string) metric $G_{\mu\nu}^{(NS)}$ which is known to be sourced by a constant NS form [9]. The gauge theoretic action is given by

$$S = \frac{-1}{(8\pi^3 g_s) \alpha'^{3/2}} \int d^5x \sqrt{-G^{(NS)}} H_{\mu\nu\lambda} H^{\mu\nu\lambda}, \quad (1)$$

where $G^{(NS)} = \det G_{\mu\nu}^{(NS)}$. The KR field dynamics H_3 is absorbed, as a torsion connection, and modifies $\nabla_\mu \rightarrow \mathcal{D}_\mu$. The modified derivative leads to an emergent description where the NS field becomes dynamical [1]. It defines a geometric torsion:

$$\begin{aligned} \mathcal{H}_{\mu\nu\lambda} &= \mathcal{D}_\mu B_{\nu\lambda}^{(NS)} + \text{cyclic in } (\mu, \nu, \lambda), \\ &= H_{\mu\nu\rho} B_\lambda^{(NS)\rho} + H_{\mu\nu\alpha} B_\rho^{(NS)\alpha} B_\lambda^{(NS)\rho} + \dots \end{aligned} \quad (2)$$

The $U(1)$ gauge invariance of \mathcal{H}_3^2 under NS field transformation incorporates a symmetric $f_{\mu\nu} = \bar{\mathcal{H}}_{\mu\alpha\beta} \mathcal{H}^{\alpha\beta}_\nu$ correction which in turn defines an emergent metric: $G_{\mu\nu}^{EG} = G^{(NS)} \pm f_{\mu\nu}$. The generic curvature tensors are worked out using the commutator of the modified derivative operator:

$$\begin{aligned} [\mathcal{D}_\mu, \mathcal{D}_\nu] A_\lambda &= (\mathcal{R}_{\mu\nu\lambda}{}^\rho + \mathcal{K}_{\mu\nu\lambda}{}^\rho) A_\rho - 2\mathcal{H}_{\mu\nu}{}^\rho \mathcal{D}_\rho A_\lambda, \\ [\mathcal{D}_\mu, \mathcal{D}_\nu] \psi &= -2 \mathcal{H}_{\mu\nu}{}^\rho \mathcal{D}_\rho \psi, \end{aligned} \quad (3)$$

where $\mathcal{R}_{\mu\nu\lambda}{}^\rho$ denotes the Riemann tensor. For a constant metric the Riemann tensor becomes trivial. \mathcal{H}_3 ensures a NS field dynamics in an emergent metric scenario. The fourth order curvature tensor $\mathcal{K}_{\mu\nu\lambda\rho}$ can be splitted into a pair symmetric and a pair non-symmetric under an interchange of first and second pair of indices. The irreducible

curvatures have been worked out [4] to obtain emergent NP-theory of gravity for onshell NS field.

Mass generation as a non-perturbation effect: We begin with a NP-theory of emergent gravity in $(4+1)$ -dimensions underlying a geometric torsion \mathcal{H}_3 in 1.5 order formulation [4]. The effective action has been shown to govern a NS field dynamics in an emergent first order (perturbation) gauge theory and a local geometric torsion \mathcal{H}_3 in a second order NP-theory. It is given by

$$S_{NP} = \frac{1}{\kappa'^3} \int d^5x \sqrt{-g} \left(\mathcal{K} - \frac{1}{48} \mathcal{F}_4^2 \right),$$

where $\mathcal{F}_4 = \sqrt{2\pi\alpha'} (d\mathcal{H}_3 - \mathcal{H}_3 \wedge \mathcal{F}_1)$, (4)

Equivalently the emergent theory may be described by the geometric form(s). We set $\kappa'^2 = (2\pi\alpha') = 1$ in the article. Then the effective actions are:

$$\begin{aligned} S_{NP} &= -\frac{1}{12} \int \sqrt{-g} \left(\mathcal{H}_{\mu\nu\lambda} \mathcal{H}^{\mu\nu\lambda} + 6(\mathcal{D}_\mu \psi)(\mathcal{D}^\mu \psi) \right), \\ &= -\frac{1}{4} \int \sqrt{-g} \left(\mathcal{F}_{\mu\nu} \mathcal{F}^{\mu\nu} + 2(\mathcal{D}_\mu \psi)(\mathcal{D}^\mu \psi) \right). \end{aligned} \quad (5)$$

The first term, in all three actions (4)-(5), sources an emergent metric and hence a torsion free geometry in absence of the second term there. A propagating geometric torsion is described by the second term which is indeed a dynamical NP-correction. The emergent curvature scalar \mathcal{K} and its equivalent Lorentz scalars constructed from the geometric forms \mathcal{H}_3 and \mathcal{F}_2 can govern an emergent metric. Each of them possess three local degrees in an emergent first order formulation. The \mathcal{F}_4 is Poincare dual to a dynamical axionic scalar field ψ and possesses one local degree in an emergent second order formulation. Together they describe four local degrees in a NP-theory of emergent theory of gravity in $5D$. In addition the NP-formulation is described by an appropriate topological coupling from:

$$\left(B_2^{(KR)} \wedge \mathcal{H}_3, B_2^{(NS)} \wedge H_3, B_2^{(NS)} \wedge \mathcal{F}_2 \wedge d\psi \right).$$

A geometric \mathcal{F}_2 in an emergent theory underlies the $U(1)$ gauge symmetry and is given by

$$\mathcal{F}_{\mu\nu} = (\mathcal{D}_\mu A_\nu - \mathcal{D}_\nu A_\mu) = (F_{\mu\nu} + \mathcal{H}_{\mu\nu}{}^\lambda A_\lambda), \quad (6)$$

where $F_{\mu\nu} = (\nabla_\mu A_\nu - \nabla_\nu A_\mu)$. The geometric forms \mathcal{F}_2 and \mathcal{H}_3 are worked out for their gauge theoretic counter-parts. The Lorentz scalar for a geometric two form may be re-expressed with a mass (squared) matrix represented by a symmetric (emergent) curvature tensor of order two. It is given by

$$\mathcal{F}_{\mu\nu}^2 = \left(F_{\mu\nu}^2 - \mathcal{K}^{\mu\nu} A_\mu A_\nu + \frac{\epsilon^{\mu\nu\lambda\alpha\beta}}{\sqrt{-g}} A_\mu F_{\nu\lambda} \mathcal{F}_{\alpha\beta} \right), \quad (7)$$

where the symmetric curvature tensor of order two may be expressed in terms of a geometric 3-form and its Poincare dual. They are:

$$\mathcal{K}^{\mu\nu} = -\frac{1}{4} \mathcal{H}^{\mu\alpha\beta} \mathcal{H}_{\alpha\beta}{}^\nu = \left(g^{\mu\nu} \mathcal{F}_2^2 + 2\mathcal{F}^{\mu\lambda} \mathcal{F}_{\lambda}{}^\nu \right). \quad (8)$$

The geometric two form in an emergent nonperturbation theory (5) is replaced by the gauge theoretic forms (7). A priori the effective non-perturbative dynamics is re-expressed as:

$$S_{\text{NG}} = -\frac{1}{4} \int \sqrt{-g} \left[F_{\mu\nu}^2 - \mathcal{K}^{\mu\nu} A_\mu A_\nu + 2(\nabla_\mu \psi)^2 \right] + \int \left(A_1 \wedge F_2 \wedge F_2 - B_2^{(NS)} \wedge H_3 \right). \quad (9)$$

At a first sight the emergent curvature tensor $\mathcal{K}^{\mu\nu}$ appears to a mass (squared) matrix. A count for the local degrees enforces $\mathcal{F}_4 = 0$ in the effective gauge theory (9). Thus a geometric torsion turns out to be a constant which in turn defines a perturbative vacuum. However $\mathcal{F}_4 \neq 0$ in an emergent gravity (8) turns out to be non-trivial. Alternately the perturbative gauge vacuum may be realized in a gauge choice for $\mathcal{F}_4 = 0$. A constant \mathcal{H}_3 leads to a constant $\mathcal{K}^{\mu\nu}$ which is diagonalized. Thus $\mathcal{K}^{\mu\nu}$ is proportional to $g^{\mu\nu}$ in a perturbation theory:

$$\mathcal{K}^{\mu\nu} = m_1^2 g^{\mu\nu} = \frac{1}{5} g^{\mu\nu} \mathcal{K}, \quad (10)$$

where m_1^2 is a proportionality constant. It assigns a mass to A_μ at the expense of a dynamical non-perturbative correction. Interestingly the non-perturbative tool to generate a mass for a gauge field is remarkable. In fact it helps to generate mass $m_p = \sqrt{\mathcal{K}/d}$ for a generic higher p -form field in a gauge theory in d -dimensions. Furthermore a mass m_1 can also be derived from a geometric two form in an appropriate combination (8). With a proportionality constant \tilde{m}_1^2 : the symmetric tensor $\mathcal{K}^{\mu\nu} = \tilde{m}_1^2 g^{\mu\nu}$ and the curvature scalar $\mathcal{K} = 3\mathcal{F}_{\mu\nu}^2$. Then the mass \tilde{m}_1 for A_μ field is re-expressed generically in d -dimensions. It is given by

$$\tilde{m}_1^2 = \frac{d-2}{d} \mathcal{F}_{\mu\nu}^2. \quad (11)$$

It can be checked that $\tilde{m}_1 = m_1$ and hence the mass of an one form is uniquely defined in a perturbative gauge theory using a NP-technique. The Poincare dual of four form ensures that the local degree of an axionic scalar signifying a NP-dynamics is absorbed to generate a massive gauge field in a perturbation gauge theory which is equivalently described by a massless gauge field in a NP-theory of emergent gravity.

The correspondence signifies a strong-weak coupling duality symmetry [32] in an emergent gravity underlying a strongly coupled NP-theory and a weakly coupled perturbation theory. Interestingly the axion in a NP-theory may be identified with a goldstone boson in a spontaneous local $U(1)$ symmetry breaking phase of a perturbative vacuum. Then the effective action (5) in a weakly coupled gauge theory may formally be re-expressed as:

$$S_{\text{PG}} = -\frac{1}{4} \int d^5x \sqrt{-G} \left(F_2^2 - m_1^2 A^2 \right) - \int \left(A_1 \wedge F_2 \wedge F_2 + B_2^{(KR)} \wedge \mathcal{H}_3 \right), \quad (12)$$

where $\mathcal{F}_2 \rightarrow F_2$ in a perturbation gauge theory. Importantly a massless gauge field A_μ in an emergent non-perturbation theory of gravity in $5D$ becomes massive at the expense of a non-perturbative dynamics. The non-perturbative tool for mass generation of a gauge field in a perturbative vacuum is remarkable and appears to be a generic feature for higher forms. It is believed to be a viable NP-tool to explore new physics underlying a strong-weak coupling duality. A massive gauge field dynamics for its Poincare dual is worked out to assign a mass m_2 to the KR field in a perturbative gauge theory. Computation of mass (squared) matrix for a NS field may directly be worked out from the curvature scalar:

$$\mathcal{K} \approx -\frac{1}{4} \left(H^\lambda{}_{\alpha\beta} H^{\alpha\beta}{}_\rho \right) B_{\delta\lambda}^{(NS)} B_{(NS)}^{\delta\rho}. \quad (13)$$

In a gauge choice for a nonpropagating geometric torsion, the gauge theoretic H_3 turns out to be a constant for a perturbative vacuum within a non-perturbative formulation. This is due to a fact that the NS field is covariantly constant on a D_4 -brane where ∇_μ is an appropriate covariant derivative. Thus the mass (squared) matrix for the NS field in eq(13) can be diagonal and hence is proportional to $g^\lambda{}_\rho$. It implies

$$\left(H^\lambda{}_{\alpha\beta} H^{\alpha\beta}{}_\rho \right) = m_2^2 g^\lambda{}_\rho. \quad (14)$$

At this juncture we recall a transition from the KR gauge theory on a D_4 -brane defined with a constant NS background with that of a NP-formulation of an emergent gravity on gravitational pair of $(3\bar{3})$ -brane [1, 2]. Generically it underlies a correspondence between a non-perturbation emergent gravity on a gravitational pair of $(4\bar{4})$ -brane and a perturbation CFT on a D_5 -brane. The boundary/bulk correspondence NP_5/CFT_6 may be summarized with the relevant forms:

$$\left[\mathcal{H}_3, \mathcal{F}_4, B_2^{(KR)} \right]_{\text{NP}} \longleftrightarrow \left[H_3, B_2^{(NS)} \right]_{\text{CFT}}. \quad (15)$$

Primarily the dynamical correspondence is between a KR form in the world-volume gauge theory and a NS form in superstring theory. Eq(14) further ensures that a mass for NS-field is sourced by the KR field dynamics. Similarly the analysis, followed from the derivation of an effective action (12), confirms that a mass for KR field is indeed sourced by a NS field dynamics. Both of them are two forms and they are different due to their differences in backgrounds or connections. Intuitively the dynamical correspondence (15) leading to two different formulations may be viewed with a single two form with two different names for their masses in a perturbative vacuum.

The dynamical correspondence between a perturbative gauge theory and a non-perturbative emergent gravity is remarkable. It signifies a strong/weak coupling duality [32] between the two different formulations underlying a two form gauge theory. The NP-theory of emergent gravity is purely governed by \mathcal{H}_3 and hence generically describes a torsion geometry. However in a gauge choice

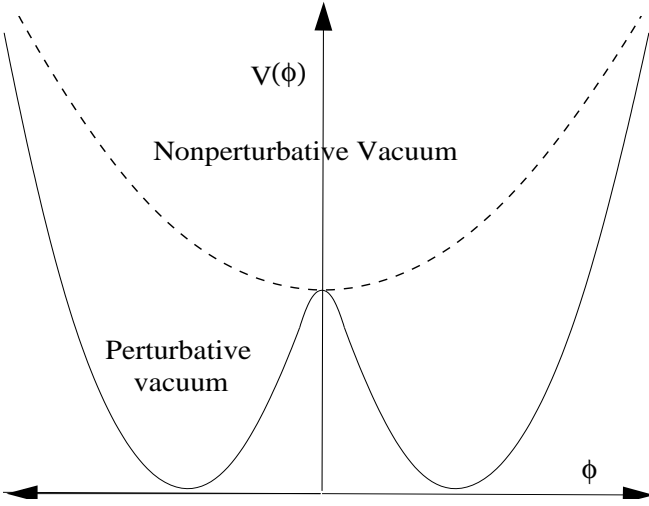


FIG. 1: Potential variation shows that a non-perturbative stable vacuum may be viewed as a perturbative unstable vacuum

$\mathcal{F}_4 = 0$, the emergent gravity describes a torsion free geometry purely sourced by a dynamical NS field.

A realization of perturbative vacuum (12) within a NP-theory may be described for a KR field. It is given by

$$S_{\text{PG}} = -\frac{1}{12} \int d^5x \sqrt{-G} \left(H_{\mu\nu\lambda} H^{\mu\nu\lambda} - m_2^2 B_{(KR)}^2 \right) - \int \left((\mathcal{F}_2 - B_2^{(NS)}) \wedge H_3 \right). \quad (16)$$

The first term in the bulk topological action is a total divergence. However it regains significance at the $4D$ boundary where the coupling $(B_2 \wedge \mathcal{F}_2)$ may be identified with the BF topological theory as discussed in refs[33, 34]. A massive KR form in a perturbation gauge theory is generated by a NP-correction sourced by a propagating geometric torsion which turns out to be an axion in $5D$. The NP-tool to generate mass for a form field underlying a geometric torsion in 1.5 order formulation is thought provoking.

The emergent gravity scenarios [1–3, 24–31] ensure that all the NP-phenomena are sourced by a lower dimensional D_p -brane whose fundamental unit is a D -instanton. Interestingly, in a recent article [4], the NP-phenomenon has been shown to be sourced by the dynamics of \mathcal{H}_3 potential in 1.5 order formulation. Dynamical effect incorporates a quantum correction to the torsion free vacua underlying an emergent metric. The correction breaks the Riemannian geometry and hence is hidden to the GTR underlying an emergent 3-brane universe within a gravitational pair $(3\bar{3})$ -brane.

The NP-idea leading to mass generation suggests that a dynamical axion (quintessence) or generically a higher-essence is hidden to an emergent 3-brane universe and hence its significance to the GTR can only be revealed with a topological coupling.

Higgs mechanism in emergent gravity: We begin by recalling the perspectives of a CFT underlying a KR gauge theory on a D_5 -brane. The gauge theoretic vacuum may equivalently be described by an a prior massless NS form in an emergent $6D$ perturbation theory [30]. A pair-symmetric emergent curvature tensor of order four has been shown to be sourced by a NS field in an emergent (first order) perturbation theory and possesses six local degrees. It has been shown to describe a torsion free geometry and has been argued to describe a Riemann type curvature in $6D$. A dynamical correction by $\tilde{\mathcal{F}}_4^2$ in an emergent gravity theory incorporates four non-perturbative local degrees. The effective dynamics is described by ten local degrees and is given by

$$S = \int d^6x \sqrt{-\tilde{g}} \left(\tilde{\mathcal{K}} - \frac{1}{48} \tilde{\mathcal{F}}_4^2 \right). \quad (17)$$

Interestingly the local degrees of a NS field in $6D$ precisely match with the local degrees of a metric tensor in $5D$ and a scalar field presumably underlying a quintessence. Generically a two form (NS field) theory in the bulk can completely be mapped to the boundary dynamics underlying a metric tensor and a scalar field ϕ . The bulk/boundary correspondence in an emergent gravity formulation on a gravitational pair of $(4\bar{4})$ -brane is remarkable. It is believed to attribute Riemannian geometry possibly at the expense of a local $U(1)$ gauge symmetry. We digress to mention that attempts have been made to use the gauge principle to realize Riemannian geometry in the recent past [35]. The effective action in the case is given by

$$S = \int_{4\bar{4}} d^5x \sqrt{-G} \left(\mathcal{R} - \frac{1}{4} \mathcal{F}_{\mu\nu} \mathcal{F}^{\mu\nu} - (\mathcal{D}_\mu \Phi)^* (\mathcal{D}^\mu \Phi) - V(\Phi, \Phi^*) \right). \quad (18)$$

The complex scalar field: $\Phi = \frac{1}{\sqrt{2}}(\phi + i\psi)$ is defined with two real scalar fields where ψ denotes an axionic scalar sourced by a NP-correction. A geometric two form in $5D$, though derived from a NP-dynamics in $6D$, describes a perturbative field strength. This is due to fact that the \mathcal{H}_3 dynamics can not be realized by \mathcal{F}_2 in $5D$. The canonical potential V is sourced by the gravitational interaction in $6D$. An explicit form may be assigned to V by taking an account for the self-interaction of the complex scalar field with a wrong sign for the mass term underlying an unstable perturbative vacuum. It may suggests that Higgs mechanism may find a natural place on a gravitational pair of $(4\bar{4})$ -brane. The potential may explicitly be given by

$$V(\Phi, \Phi^*) = \left(m^2 (\Phi^* \Phi) - \lambda^2 (\Phi^* \Phi)^2 \right), \quad (19)$$

where m and λ are real constants. The emergent theory (18) with the potential (19) remains invariant under a global $U(1)$ symmetry: $\Phi \rightarrow e^{i\theta} \Phi$. The global $U(1)$ is replaced with a local $U(1)$ symmetry with a minimal gauge coupling in the action: $D_\mu \equiv (\partial_\mu + ieA_\mu)$. Explicitly the dynamics leading to an unstable vacuum is given by

$$S = - \int_{4\bar{4}} d^5x \sqrt{-G} \left[\mathcal{R} - \frac{1}{4} \mathcal{F}_{\mu\nu}^2 - (D_\mu \Phi)^* (D^\mu \Phi) - m^2 (\Phi^* \Phi) + \lambda^2 (\Phi^* \Phi)^2 \right]. \quad (20)$$

The interaction energy function $V(\Phi^*, \Phi)$ at its minima satisfies an equation of a circle:

$$\phi_{\min}^2 + \psi_{\min}^2 = \left(\frac{m}{\lambda}\right)^2.$$

Thus a large number of stable ground/vacuum states, underlying the local $U(1)$ symmetry, are described by the circle equation. Any particular vacuum state, *i.e.* $\phi_{\min} = (m/\lambda)$ and $\psi_{\min} = 0$, spontaneously breaks the local $U(1)$ symmetry in an emergent geometric theory. In fact the local symmetry breaking phenomenon, *i.e.* Higgs mechanism, takes place at the event horizon of an emergent black hole which is identified as a stable vacuum.

A shift from an unstable (a non-perturbation) vacuum (22) to a stable (perturbative) vacuum may be realized with redefined real scalar fields: $\eta = \phi - (m/\lambda)$ and $\xi = 0$. The action is re-expressed in terms of η and ξ fields for a stable vacuum and is known to generate mass term for the gauge field A_μ in addition to a few non-sensible interactions. For instance see a text book [7] for the detailed nature of interactions in the symmetry breaking phase underlying the Higgs mechanism. The non-sensible interaction terms can be gauged away completely by the local $U(1)$ invariance under $\Phi \rightarrow \Phi'$ in the action (22). In a gauge choice: $\Phi' = (\phi \cos \theta - \psi \sin \theta)$, *i.e.* restricting to the real parts, the complete perturbation theory on a gravitational pair is given by

$$S_{\text{PG}} = \int_{4\bar{4}} d^5x \sqrt{-G} \left[\left(\mathcal{R} - \frac{m^4}{4\lambda^2} \right) + \frac{e^2}{2} \left(\eta + \frac{m}{\lambda} \right)^2 A^2 - \frac{1}{4} \mathcal{F}_{\mu\nu}^2 - \frac{1}{2} (\mathcal{D}\eta)^2 + \frac{1}{2} m^2 \eta^2 + (m\lambda) \eta^3 + \frac{1}{4} \lambda^2 \eta^4 \right] \quad (21)$$

It implies that a cosmological constant appears to possess its origin in the symmetry breaking phase and is sourced by the Higgs mechanism. Keeping a track for the four local degrees in $5D$ emergent gravity, the effective dynamics may explicitly be given on a 4-brane within a vacuum pair of gravitational brane/anti-brane. Thus some of the undesirable emergent curvatures are assigned to an anti 4-brane. It is equivalent to a consistent truncation of the effective action defined with a massive gauge field. It may suggest that the analysis under a CFT leads to a study of Higgs mechanism naturally in an emergent gravity in $5D$. Then the effective dynamics on an emergent gravitational 4-brane in presence of a background $\bar{4}$ -brane is re-expressed as:

$$S_{\text{PG}} = -\frac{1}{4} \int_4 d^5x \sqrt{-G} \left[\mathcal{F}_{\mu\nu}^2 - \frac{e^2}{2} \left(\eta + \frac{m}{\lambda} \right)^2 A^2 \right] + \int_{\bar{4}} d^5x \sqrt{-G} \left[\left(\mathcal{R} - \frac{m^4}{4\lambda^2} \right) - \frac{1}{2} (\mathcal{D}\eta)^2 + \frac{1}{2} m^2 \eta^2 + (m\lambda) \eta^3 + \frac{1}{4} \lambda^2 \eta^4 \right]. \quad (22)$$

The gauge field on an emergent 4-brane universe acquires a mass $M = \frac{e}{\sqrt{2}} \left(\eta_0 + \frac{m}{\lambda} \right)$ via Higgs mechanism where the Higgs field takes a constant η_0 there. Apparently the local degree of the self interacting Higgs scalar is described on an anti 4-brane and is hidden to the 4-brane-universe. Thus the Higgs field, underlying a NP-formulation of emergent gravity, may be identified with a missing scalar in a $5D$ metric theory. It is inspiring to interpret the Higgs scalar as a hidden-essence to the gravitation theory in $5D$. The scalar field, being a generalized coordinate, determines the thickness of the brane/anti-brane configuration.

In a NP-decoupling limit a gravitational 4-brane becomes independent from the anti 4-brane and hence $\eta \rightarrow \eta_0$. The effective dynamics of a 4-brane and anti 4-brane are approximated in the limit to yield:

$$S_4 \rightarrow -\frac{1}{12} \int d^5x \sqrt{-G} \left(\mathcal{H}_{\mu\nu\lambda}^2 - \tilde{M}^2 B_{(NS)}^2 \right) \quad \text{and} \quad S_{\bar{4}} \rightarrow \int d^5x \sqrt{-G} \left(\mathcal{R} - \Lambda \right), \quad (23)$$

where $\Lambda = (m^4/4\lambda^2)$ is a constant. A mass for a NS field ensures a short range interactions. Thus the effective dynamics on a 4-brane may be identified with a weak interacting phase for the NS boson in a decoupling limit. Remarkably an anti 4-brane effective dynamics is purely governed by the Riemannian geometry in the limit. Generically the action (22) signals a “gravito-weak” phase within a NP-theory.

Furthermore the emergent gravity on a 4-brane may further be viewed on a gravitational pair of (3 $\bar{3}$)-brane. The effective action is given by

$$S_{\text{PG}} = -\frac{1}{12} \int_3 d^4x \sqrt{-G} \left(\mathcal{H}_3^2 - \tilde{M}^2 B_{(NS)}^2 \right) - \frac{1}{4} \int_{\bar{3}} \sqrt{-G} \mathcal{F}_2^2 - \int_{3\bar{3}} B_2^{(NS)} \wedge \mathcal{F}_2. \quad (24)$$

Four local degrees in $5D$ may rightfully be governed by two local degrees of a massive NS field on an emergent 3-brane and two for a massless gauge field A_μ on an anti 3-brane. This is due to a fact that GTR and their parallel are described by two local degrees each in an emergent scenario. Two local degrees of a massive NS field in (3+1)-dimensions is a NP-phenomenon as the mass is generated by a NP-local degree in $5D$. The correspondence between the NS-field in $5D$ and a metric field in $4D$ with a quintessence scalar further re-confirms two local degrees of a massive NS field in (3+1)-dimensions. It suggests that the massive NS field quanta in (3+1)-dimensions with a hidden NP-axion may be a potential candidate to describe a graviton in $4D$.

A mass for a NS field in the action (24) ensures that an emergent 3-brane may formally be identified with the weak interacting NS boson, whose role is analogous to the

gauge bosons (W^\pm, Z^0) in standard model for particle physics. The dynamics on an anti 3-brane governs an $U(1)$ gauge theory and may be identified with an EM-vacuum. Remarkably the complete dynamics (24) may a priori be viewed via “electro-weak” interactions.

On the other hand the topological term in eq(24) precisely describes a coupling between an emergent gravitational 3-brane and an anti 3-brane within a vacuum pair. Generically an emergent gravity on a 3-brane underlying a Riemann curvature may be derived from the anti 4-brane (23). In a decoupling limit the quintessence freezes to describe the GTR. For constant values: $\eta_1 > \eta_0 > \eta_{-1}$, *i.e.* for $\eta_1 = (1.707)\eta_0$ and $\eta_{-1} = (0.293)\eta_0$, the non-perturbation correction decouples to yield:

$$S_3 = \int d^4x \sqrt{-G} \left(\mathcal{R} - \Lambda_{\text{eff}} \right), \quad (25)$$

$$\text{where } \Lambda_{\text{eff}} = \Lambda - \frac{\eta_0^2}{2} \left[(m + \lambda\eta_1)(m + \lambda\eta_{-1}) \right].$$

Thus the Higgs scalar in a NP-decoupling limit ensures a small cosmological constant. Analysis suggests that the Einstein-Hilbert action in presence of a small non-zero value for Λ_{eff} may alternately be realized by the Higgs phase of NS field presumably underlying a “gravito-weak” interaction on a gravitational pair of $(3\bar{3})$ -brane. The Higgs scalar η and the scalar derived from \mathcal{R} in eq(23) are identified as the quintessence(s) for two emergent pairs of $4D$ brane dynamics. Presumably it provides a hint towards four parallel brane-universes in $4D$ underlying a NP-theory in $6D$. The unification idea [36] underlying a two form CFT is thought provoking and is believed to reveal new physics.

Acknowledgements: Author (SK) acknowledges the research and development grant by the University of Delhi, India. A preliminary version of the research was presented by the author (RN) in an International Conference on “New Trends in Field Theories 2016 November 06-10” at the Banaras Hindu University, Varanasi, India. Authors gratefully acknowledge various discussions in general during the conference.

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